

Durham Research Online

Deposited in DRO:

27 August 2019

Version of attached file:

Accepted Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Harris, R. and Moffat, J. and Evenhuis, E. and Martin, R. and Pike, A. and Sunley, P. (2019) 'Does spatial proximity raise firm productivity? evidence from British manufacturing.', Cambridge journal of regions, economy and society., 12 (3). pp. 467-487.

Further information on publisher's website:

<https://doi.org/10.1093/cjres/rsz017>

Publisher's copyright statement:

This is a pre-copyedited, author-produced PDF of an article accepted for publication in Cambridge journal of regions, economy and society following peer review. The version of record Harris, R , Moffat, J, Evenhuis, E, Martin, R Pike, A Peter Sunley (2019). Does Spatial Proximity Raise Firm Productivity? Evidence from British Manufacturing. Cambridge Journal of Regions, Economy and Society 12(3): 467-487 is available online at:
<https://doi.org/10.1093/cjres/rsz017>

Additional information:

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in DRO
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full DRO policy](#) for further details.

Does Spatial Proximity Raise Firm Productivity? Evidence from British Manufacturing

Richard Harris^a, John Moffat^a, Emil Evenhuis^b, Ron Martin^c, Andy Pike^d, Peter Sunley^b

The United Kingdom's economy is one of the most regionally imbalanced in Europe. The government's recent industrial strategy discusses various means of addressing this, one of which is the strengthening of existing clusters. Using plant-level indices of spatial proximity derived from postcode district data, this paper investigates the extent of spatial concentration and its impact on total factor productivity in advanced manufacturing sectors in Great Britain. The results from estimation of production functions indicate that, in most advanced manufacturing sectors, spatial concentration has a negative impact on productivity in small plants and a positive effect in larger plants. Large plants likely benefit more from knowledge spillovers due to their higher levels of absorptive capacity.

Keywords Spatial proximity Clustering Externalities Firm productivity British manufacturing

JEL Classification. R12 D24 L25

^a Department of Economics & Finance, Durham University, Mill Hill Lane, DH1 3LG.
r.i.d.harris@durham.ac.uk; john.moffat@durham.ac.uk.

^b Department of Geography, University Road, University of Southampton, Southampton SO17 1BJ
E.Evenhuis@soton.ac.uk P.J.Sunley@soton.ac.uk

^c Department of Geography, University of Cambridge, Downing Place CB2 3EN rlm1@cam.ac.uk

^d Centre for Urban and Regional development Studies, Newcastle University NE1 7RU
andy.pike@newcastle.ac.uk

This paper is funded under the ESRC project "Manufacturing renaissance in industrial regions? Investigating the potential of advanced manufacturing for sectoral and spatial rebalancing" ES/P003923/1. We would like to thank an anonymous referee for their comments; any remaining errors remain with the authors.

This work contains statistical data from the ONS which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's printer for Scotland. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates.

Introduction

Ever since Michael Porter's influential work advanced the claim that the geographical clustering of similar and related interconnected businesses raises their competitive advantage (for example Porter, 1990, 1998a,b), the general assumption has been that firms inside such clusters will have higher productivity than those outside. As Porter himself puts it:

Clusters affect competition in three broad ways: first, by increasing the productivity of companies based in the area; second, by driving the direction and pace of innovation, which underpins future productivity growth; and third, by stimulating the formation of new businesses, which expands and strengthens the cluster itself (Porter, 1998, p.)

Four main advantages are alleged to be associated with the spatial proximity of similar and related firms: access to a pool of specialised labour, expertise and suppliers; access to and transfer of specialised information and knowledge; the attraction and emergence of various complementarities (from products to marketing to dependent businesses and activities); and access to specialised institutions and public goods (such as universities and transport infrastructure).¹

The UK is among several countries that have adopted or pursued some form of cluster policy over recent decades. In the UK, it was an explicit element of the New Labour governments' approach to national and regional industrial policy between 1997 and 2010 (DTI, 1998; DETR, 2000). Indeed, Michael Porter was an advisor to the then Department of Trade and Industry, and the Regional Development Agencies that were established under New Labour also drew heavily on Porter's cluster theory. Around 2004, however, the scale at which regional industrial development policy was focused shifted from regions to city regions, and cluster policies became much less visible (Swords, 2013). With the abolition of the Regional Development Agencies under the Conservative-LibDem coalition government in 2010, this de-emphasis on cluster based industrial policy continued. More recently, clusters have resurfaced as part of the Conservative Government's recent embrace of industrial policy as a means of achieving its stated goal of spatially rebalancing the national economy and addressing the UK's poor productivity performance (DBEIS, 2017). Thus, according to the UK Government "Clustering is viewed as beneficial to firms (particularly to small firms) because they can access a shared pool of expertise and labour, suppliers, and information or contacts." (HC, 2018).

Apart from the issues of identifying clusters and how, exactly, cluster policies can best be operationalised (what, precisely, should such policies do?), there is the question of how much empirical support there actually is that firms that co-locate benefit. The belief that spatial proximity produces advantages for firms that raise their productivity is fundamental to most cluster strategies, as it is typically assumed that spatial proximity and co-location support firms' learning and the development of beneficial inter-linkages. However, the empirical evidence is by no means unequivocal (see Duranton, 2011). In the innovation literature, it has been argued that spatial proximity *per se* does not always raise interactive learning and innovation (Boschma, 2005). In some cases, spatial proximity does not lead to the formation of inter-linked and collaborative clusters of firms, and in other cases it may actually restrict and constrain firm learning. There is

hence an analytical need to distinguish the effects of spatial proximity on productivity and to examine how spatial or geographical proximity interacts with other dimensions of firm proximity such as cognitive, organisational and social proximities.

Set against this background, our aim in this paper is to test how far spatial proximity raises firm productivity in the case of knowledge-intensive British manufacturing. We analyse plant-level total factor productivity using data from the Annual Business Survey for office machinery and data processing equipment, electrical and electronic engineering, motor vehicles and motor vehicle parts, instrumental engineering, pharmaceuticals and aerospace equipment and repairing, over the period 1984-2016. To examine the effects of different degrees of spatial co-location we construct a spatial proximity index that measures the proximity of each plant to every other plant within the same industry, and then use this to test if plants with high values of the index (a high degree of spatial concentration) have higher total factor productivity (TFP). Since intra-industry externalities are only one element of what is understood to be the potential localisation economies that can come from the co-location of plants, inter-industry externalities that take account of potential effects from the co-location of plants in related industries are also modelled. We find that the productivity benefits from spatial proximity are by no means universal, and in many cases only exist for larger plants (with sufficient absorptive capacity). This runs counter to the claim, referenced above, that spatial co-location and clustering are particularly beneficial for small firms and therefore raises some important caveats concerning the benefits that might be expected from the pursuit of cluster policies as a component of the Government's new Industrial Strategy.

We would argue this paper makes three major contributions to the literature. First, we measure intra-industry effects and effects arising across related industries using plant-level distance indices, rather than the aggregate measures commonly used in other studies that require *a priori* specification of the spatial area in which spillovers and interactions occur. Second, plant-level data are used and therefore we are able to directly test the extent to which each plant's TFP is determined by the degree to which it is co-located with other plants in the same and/or related industries. And third, we recognize the need to treat location as endogenous, and thus each distance index used is instrumented when undertaking econometric modelling.

In the next section we review the literature on the possible externalities associated with different types of spatial proximity, and their effects on firm performance. We then discuss the data and model specification used to examine the effect of spatial proximity on total factor productivity of plants in six advanced manufacturing sectors in Britain. In the subsequent section, the baseline findings are presented; followed by a discussion of results obtained from different specifications with regard to the 'distance decay' of the possible externalities, as well as whether clusters are narrowly defined, or more broadly (i.e., when also including related industries). Based on these results, we consider the potential implications for place-based policies targeting clusters, specifically in light of the UK's Industrial Strategy and concomitant local industrial strategies.

Identifying and measuring the externalities from spatial proximity²

As we have noted, the contention that the spatial proximity of similar firms acts to raise their productivity was basic to Michael Porter's formulation of the cluster concept and has been central to most accounts of the benefits of clusters.³ According to Porter (1996), clusters raise the productivity of firms primarily through dynamic externalities related to learning, rather than by static cost-reducing externalities. This contention has been supported and reinforced by theoretical work on agglomeration economies more generally, in relation to the benefits that accrue to firms and plants from being located in the vicinity of large concentrations of other firms and plants. These benefits can be summarised as being processes of 'sharing', 'matching' and 'learning' (Duranton and Puga, 2004; Overman *et al.*, 2009). Agglomeration benefits arise through sharing when firms benefit from drawing on a common pool of resources, such as indivisible goods or facilities, a wide variety of input suppliers, a larger pool of labour, as well as the sharing of risk across plants. The probability, and the speed, of matching is also improved in areas with many firms and workers. Finally, the diffusion and accumulation of knowledge is expected to be better in areas with a high density of both firms and workers. By facilitating face-to-face contact, the concentration of both workers and entrepreneurs in a cluster can facilitate spillovers and the transfer of knowledge. In addition, workers will find it easier to move from one firm to another. This process will assist in the transfer of knowledge (i.e., 'learning') across firms (see e.g. Acs *et al.*, 2002; Anselin *et al.*, 1997; Audretsch and Feldman, 1996). It is possible that industry clusters – specialised localised concentrations of firms in the same or closely related sectors – benefit from all three of these processes.

Providing empirical assessment of this possibility is much more challenging. There has, of course, been considerable ambiguity about the definition of clusters and their spatial extent (Martin and Sunley, 2003), and it is difficult to disentangle the effects of spatial proximity from other forms of firm proximity. While Porter's approach suggests that clusters are sets of related industries, many others have assumed that clusters are essentially based on localisations of single industries and thus have assumed that clusters benefit primarily from Marshallian (intra industry) localisation economies (Marshall, 1890; Arrow, 1962; Romer, 1986). Such MAR-spillovers, it is argued, lead to specialization (Audretsch *et al.*, 2007), since they suggest that firms within a specific industry locate near other firms along the supply chain (be they customers or suppliers); locate near other firms that use similar specialised labour; and/or locate near other firms that might share knowledge (Ellison *et al.*, 2010). However, if clusters consist of wider groups of interrelated industries they may also benefit from some inter-industry spillovers across linked or related industries, which might be conventionally subsumed under Jacobsian or urbanization spillovers. The distinction between intra- and inter-industry spillovers is somewhat blurred if related industries (that are linked technologically or by close upstream and downstream dependencies, or which share labour or knowledge) are classified as part of a 'cluster' (see Delgado *et al.*, 2014). We return to this type of 'related spillover' later in our discussion.

However, the empirical evidence on whether spatial proximity does act to raise firm productivity is not as strong as either cluster theory or agglomeration theory would lead us to expect. Robust empirical studies are relatively scarce (Duranton, 2011). While there has been extensive empirical research on agglomeration, most of this has been framed in

terms of localisation and urbanisation economies and their combinations. Many studies have sought to estimate the impact of agglomeration externalities on productivity without clearly distinguishing between localisation, cluster-based, or urban externalities. Examinations of the relations between employment and population density and productivity across local areas (usually cities) typically estimate that doubling of employment density increases labour productivity by between 3 and 6 percent (see Åberg, 1973; Sveikaukus, 1975 and Segal, 1976; Ciccone and Hall, 1996; Ciccone, 2002; Rice *et al.*, 2006). Using French area-level data, for example, Combes *et al.* (2008) estimate the impact of population density and market potential on TFP and obtain elasticities of 3.5% and 2.5% for population density and market potential respectively (also Andersson and Lööf, 2009; Wixe, 2015). While these studies provide some evidence in favour of the benefits of co-location externalities, the magnitude of the effects is generally small.

A further literature has sought to distinguish the relative importance of localisation and urbanisation externalities, but has also used area-level data. These analyses have been rather mixed and inconclusive, and also suffer from the problem that they do not specifically measure the distance between firms in the same or related industries. Some studies suggest that both types of externality have significant effects on productivity (for example, Rigby and Essletzbichler, 2002; Moomaw, 1983; Graham *et al.*, 2010). In contrast, other studies report stronger localisation economies (Henderson, 1986; Drennan, 2002; Acs *et al.*, 2002). However, other studies conclude that urbanisation externalities are more important than localisation externalities, and, indeed, report evidence of localisation *diseconomies* (Brühlhart and Mathys, 2008; Glaeser *et al.*, 1992; Quigley, 1998; van Stel and Nieuwenhuijsen, 2004; van Oort, 2007). While the evidence from studies using aggregate data suggests that both types of externality operate in some cases, in general most findings are too inconsistent, and too indirectly linked to spatial proximity to be compelling.⁴ Some studies try to explain this variation by focusing on differences between types of industry or different stages of the industry or product lifecycle (Nakamura, 1985; Faggio *et al.*, 2017). Others suggest that clustering and co-location only yield positive externalities up to a threshold, and above this begin to have a negative effect on productivity (Antonelli, *et al.*, 2011).

A substantial number of studies that use firm and micro-data evidence have found that localisation externalities and spatial proximity to firms in the same industry have a positive effect on firm productivity although other studies show mixed results (more details are provided in the online appendix). These inconsistent results may partly reflect the fact that micro-level studies have measured MAR or localisation externalities in different ways. For example, Harris and Moffat (2012) proxied MAR spillovers using the percentage of industry output (at 5-digit industry SIC level) located in the local authority district in which the plant was located. Such empirical studies typically use relatively small administrative areas, such as local authority districts since spatial productivity spillovers are assumed to have a strong distance decay; but the extent to which they are limited is likely to be an empirical issue (e.g., Gertler, 2003; Venables, 2011). Moreover, whether these small areal units correspond with the spatial dimensions of clusters is unknown. There is much uncertainty concerning the ‘correct’ geographic area needed to capture cluster externalities, and different papers use different statistics, while some experiment with different industrial agglomeration and diversification indices (see, for example, Devereux *et al.*, 2007; Baldwin *et al.*, 2010).

Attempts to estimate the productivity benefits of spatial proximity also encounter significant endogeneity problems. Clusters of co-located firms may, of course, be created by local spin-off processes, and it is not credible to simply demonstrate that a cluster exists and then deduce that proximity spillovers are benefiting firms. Higher productivity firms may also choose to locate in clusters. This issue of reverse causality is thus especially relevant when considering whether spatial proximity and colocation are a source of productivity spillovers. Greenstone *et al.* (2010) use a novel approach to overcome the problem by looking at TFP outcomes in areas that attract new large plants (e.g., multinationals) versus areas that were the second-choice location for these plants (and thus share common advantages). They conclude that there are significant productivity spillovers from the opening of new plants that are larger for firms that share labour pools and similar technologies. Therefore, in this paper we treat co-location and productivity as endogenous and instrument both sets of variables (as explained below).

Finally, a key response to the mixed and varied results of research on cluster and localisation spillovers has been to pay much more attention to firm heterogeneity (Wixe, 2015). There is mounting evidence that differences in firm characteristics mean that while some benefit from spatial proximity, other firms may gain no advantage, or even be disadvantaged by such a location (Knoben *et al.*, 2016). For example, Rigby and Brown (2015) report that smaller and younger firm benefit most from knowledge spillovers within a radius of 5km, but that older firms benefit from having upstream suppliers nearby. Others suggest that multilevel models are needed to control for firm-specific effects and their interactions (Raspe *et al.*, 2011). Some authors argue that smaller firms tend to benefit more from co-location as such firms are more dependent on local sources for inputs, knowledge and collective capabilities (Cainelli *et al.*, 2016; Raspe *et al.*, 2011). However, size may be less important than whether firms possess local connectedness and can access local resources, whether they can absorb and internalize those resources, and whether they can also utilize these resources in their production practices (Knoben *et al.*, 2016). Absorptive capacity plays a key role in these processes.

The absorptive capacity of a firm or plant especially in terms of its ability to internalise potential external knowledge spillovers (which for TFP may be more important in the long run than other sources of spillovers) is a key component of this heterogeneity. Harris and Yan (2019) conclude that firms will not fully benefit from external knowledge unless they have sufficient absorptive capacity. As Harris and Le (2018, p.1) explain “... like the ability of an individual to learn, absorptive capacity is not just about firms being able to benefit from spillovers but rather using knowledge from the external environment to improve their productivity; if firms are not able to learn, then new strategies or technology that are designed to help firms become more productive are likely to have only limited impact.” Harris and Yan, *op. cit.*, show that in the UK context, absorptive capacity levels are strongly and positively associated with firm size, especially in manufacturing (Harris and Li, 2018, show the same for New Zealand). Others have also demonstrated the importance of absorptive capacity: for example, Löf and Nabavi (2015, p. 251) report that in their study of Swedish manufacturing firms, the productivity effect from agglomeration spillovers was restricted to large, high-technology firms and foreign-owned multinational enterprises in non-high-technology sectors. They conclude that “... spillovers can also be neutral or very limited if firms lack sufficient absorptive capacity or operate in technological niches where few other firms operate in their field” (pp. 260-261). Moreover, Papalia and Bertarelli (2009, p. 163) noted in their review of

the subject – confirmed by their own results – that: “The main result emerging from these papers is that absorptive capacity is one of the most important prerequisites for transfer of firm specific advantages to domestic firms and effective linkages”. Lychagin (2016) concurs, stating that “... spillovers affect firms differently... if firms are heterogeneous in *absorptive capacity*” (emphasis in original text). Lastly, Wang and Zhao (2010) examined whether firms increase their ‘technological distance’ from competitors, especially when it is not feasible to increase their geographical distance, as a way of reducing knowledge spillovers to their competitors. They note that this is more likely to be successful when competitors lack absorptive capacity and complementary assets, which is more likely to be the case for smaller (rather than larger) plants. In this paper we therefore examine the relationships between co-location (with other firms in the same industry and in related industries), productivity, and plant size in some detail.

Finally, in order to avoid ambiguity, in this paper the emphasis is on the potential spillover benefits from localisation externalities of the MAR-type, arising from the co-location of plants within the same industry or ‘related’ industries (e.g., making up the supply-chain). The impact of both intra-industry and inter-industry spatial proximity effects are included, where inter-industry refers to ‘related’ industries⁵ (although we do also include a variable in the models estimated that seeks to measure such Jacobsian urbanization economies).

Analysis of British advanced manufacturing - data and model specification

In this study, we use plant-level panel data covering 1984-2016 from the Annual Business Survey (ABS, prior to 2008, the ABS was called the Annual Respondents’ Database)⁶ for six sectors of manufacturing (using the 1980 Standard Industrial Classification): office machinery and data processing equipment (SIC33) (henceforth referred to as ‘computers’), electrical and electronic engineering (SIC34) (henceforth abbreviated to ‘electronic engineering’), motor vehicles and motor vehicle parts (SIC35) (henceforth abbreviated to ‘motor vehicles’), instrumental engineering (SIC37), pharmaceuticals (SIC257) and aerospace equipment and repairing (SIC364) (henceforth abbreviated to ‘aerospace’). This data is collected by the UK’s Office for National Statistics (ONS) each year for calculating the national income accounts. In our econometric analysis we weight the data using sample weights to ensure that the distribution of plants for which there is financial data are representative of the population of plants operating in each year in Great Britain. Weighting is necessary both to ensure that population parameters are estimated and because of the fact that one of the endogenous variables in the model (employment) is used by the ONS as part of the stratified sampling approach to collect the ABS data; thus leading to the problem of endogenous sampling or stratification (see the appendix in Harris, 2002). Harris and Moffat (2015) describe in detail the rationale for inclusion of the variables in the model, the data (and especially the use of plants rather than firms as the unit of analysis) and the econometric methodology, and the reader is referred to the earlier article for detailed information. Below, only the core elements of the approach are set out.

The first step was estimation of Cobb-Douglas log-linear production functions (including fixed-effects, α_i) for each of the six advanced manufacturing sectors identified above. Both sides of the productivity relationship (the demand-side, covering firm market

power and thus competitive influences; and supply-side factors such as firm efficiency and technological progress) are incorporated.⁷ The model is estimated using system-GMM to address the issues of endogeneity inherent to revenue production function estimation:⁸

$$\tilde{r}_{it} \equiv y_{it} + p_{it} - p_{It} = \left(\frac{\sigma-1}{\sigma} \right) (\alpha_i + \alpha_E e_{it} + \alpha_M m_{it} + \alpha_K k_{it} + \alpha_X X_{it} + \alpha_T t) + \frac{1}{\sigma} (r_{It} - p_{It}) + u_{it} \quad (1)$$

where \tilde{r}_{it} is the natural logarithm of plant i 's revenue deflated by an *industry* price index, p_{It} , since firm-level prices, p_{it} , are unobserved; y_{it} , e_{it} , m_{it} and k_{it} refer to the natural logarithms of real gross output, employment, intermediate inputs⁹ and capital stock in plant i in time t ($i = 1, \dots, N$; $t=1, \dots, T$) respectively; X_{it} is a vector of observed variables determining TFP (as set out in Table 1) which includes the (logged) distance index (described in detail below) and an interaction between this variable and (logged) employment while t represents technical progress; the extent to which the industry experiences a mark-up (or mark-down – see Caselli *et al.*, 2018), is measured by $\sigma/(\sigma - 1)$; and u_{it} is the residual term capturing all other effects on revenue TFP. Note, we treat y_{it} (and its lagged value), e_{it} , m_{it} , k_{it} and the natural log of the spatial proximity/distance index as endogenous (and thus instrument these variables).

The source of the data used to estimate equation (1) is described in Table 1; in particular, estimates of plant level capital stock are obtained using the perpetual inventory approach and plant level estimates of real investment – the methods used are set out in Harris and Drinkwater (2000) and Harris (2005b).

Table 1 here

Figure 1 here

As discussed in section 2, MAR localisation economies are usually proxied by some aggregate measure at a predefined spatial level (e.g. the percentage of industry output located in the local authority district in which the plant was located). The approach taken in this study is to use a more direct measure of the extent to which a plant is ‘co-located’ with other plants in the same 4-digit industry or plants in related 4-digit industries.¹⁰ This is based on mapping the location of every plant and calculating the distance in kilometres between all pairs of plants in each industry/related industry grouping, using the plant’s postcode district (first 4-digits of the UK postcode) and the following formula:

$$Distance_i = \frac{1}{J-1} \sum_{j=1, j \neq i}^J e^{-x(d_{i,j})} \times \frac{E_j}{\sum_{k=1, k \neq i} E_k} \quad (4)$$

where J is the number of observations; x is the rate of decay of the function; and $d_{i,j}$ is the distance between plant i and j ;¹¹ E_j is the number of employees in plant j ; and $\sum_{k=1, k \neq i} E_k$ is the total employment in all other plants, except plant i , in the industry/related industry grouping.

From Figure 1, for plant A, using Equation (3) (and assuming a decay function of -0.05 and all plants are of equal size) gives $\frac{1}{3} (e^{-0.05(10)} + e^{-0.05(21)} + e^{-0.05(55)}) = 0.34$. The values for plants B, C, D are: 0.31, 0.26 and 0.08, respectively, and the higher is the

$Distance_i$ value, the more a plant is located in spatial proximity to other plants in the same industry.

We use $e^{-0.05(d_{i,j})}$, labelling this the ‘medium’ function, but in what follows results are also presented based on $e^{-0.01(d_{i,j})}$ (low decay) and $e^{-0.10(d_{i,j})}$ (high decay). Based along the lines of the simple example above, Figure 2 illustrates how adopting different decay functions impact on a plant’s contribution to spatial proximity as captured by the distance index ($Distance_i$); when the decay is low, a plant located a long distance from another plant (e.g., $d_{i,j} = 200$ km) still contributes a fairly large potential spillover ($e^{-0.01(200)} = 0.135$), but with low or medium decay the impact of such a distant plant on the function is effectively 0. In contrast, a plant located 20 km distant contributes the same to the overall distance index using a high rate of decay ($e^{-0.1(20)} = 0.135$), while with medium decay the plant would need to be 40 km distance to produce this same contribution.

Figure 2 here

Table 2 here

Table 2 shows which industries had the highest proximity levels (ranked on the data in column 1), with motor vehicles having the highest mean value, and pharmaceuticals being the least co-located in this period. However, there are differences in the ranking depending on which index is used (pharmaceuticals comes joint top on the basis of the inter-high index), and there are significant differences in the value of distance indices with values declining as the measure moves from a low rate of decay to a high rate of decay (measures that incorporate both the sector of interest and related sectors, see appendix, are also lower than intra-industry based indices).

Figure 3 here

To illustrate how the distance indices vary across space, Figure 3 shows the average (logged) values, obtained from the industry-level distance specification, across local authority areas in 2016, based on plants from all six sectors. Spatial proximity is strongest in areas such as London and its hinterland, the industrial heartlands of the West Midlands, and Manchester and Liverpool; but the latter is only particularly apparent with a high rate of decay, which confines spatial proximity to those (larger number of) plants that are close by.¹²

Baseline findings for the six advanced manufacturing sectors

Figure U.3 in the appendix shows the co-location of each of the six case-study advanced manufacturing sectors, using the ‘intra-medium’ distance index. Each of the sectors has both a different geography and a different degree of spatial clustering. The main results from estimating Equation (1) for the six advanced manufacturing industries are provided in Tables U.1 in the online appendix. There are six sets of results for each industry, reflecting the different measures of the distance index used (Table 1). In this section, we

concentrate on the results based on using a medium decay function, $e^{-0.05(d_{i,j})}$, and 4-digit industry co-location; however, all estimated models using various distance indices are deemed sufficient in terms of tests for over-identification (i.e., the Hansen test of validity of the instrument set used – where instruments for the endogenous variables comprised lagged values in first differences and levels; the former being used in the levels equation and the latter the first differenced equation of the system GMM model), and for autocorrelation (*cf.* the AR(1) and AR(2) test statistics).¹³ To reduce the likelihood that our estimates are biased due to the problem of over-instrumentation (see Roodman, 2009), the instrument set was ‘collapsed’.¹⁴ This had the expected effect of reducing dramatically the p-value of the Hansen test (although not to the extent that the null of valid instruments was rejected).

There is only a brief discussion of the results relating to those determinants of TFP which are not the main focus of this paper: e.g., the age of the plant, foreign-ownership and various economies-of-scale.¹⁵ With respect to the latter, we note that most sectors benefited from increasing internal returns-to-scale; only in electronic engineering is there any systematic evidence to suggest the coefficients on the factor inputs sum to less than one. Technical change was strong in computers (some 4-5% p.a.); around 1-2% p.a. in electronic engineering, motor vehicles and instrumental engineering; 0.5% in pharmaceuticals; and not statistically significant in aerospace. Older plants, *cet. par.*, generally had lower TFP (the exceptions were in computing where age was positively associated with TFP, and aerospace where it was not significant). Single-plant enterprises had higher productivity in computing, instrumental engineering and pharmaceuticals, and lower productivity in the other sectors. The effect of external economies-of-scale linked to being part of a multi-regional or multi-SIC enterprise were a mix of positive and negative (the latter was confined to multi-product firms and computing and electronic engineering, with some evidence that this extends to motor vehicles). Generally, US-owned plants had, *cet. par.*, higher TFP, as did EU-owned (but to a lesser extent); the results for ‘other’ foreign-owned are weaker but if anything suggest little or no productivity advantage (suggesting their external owners are technologically sourcing rather than exploiting – Driffield and Love, 2007). Being located in a city had mixed effects (positive for electronic engineering and instrumental engineering, negative for aerospace and insignificant otherwise), while urbanization economies were not evident in four sectors (and had a positive effect for computing, but a negative effect for aerospace). Belonging to a concentrated industry increased (decreased) TFP in three (two) sectors, while only in computing and motor vehicles was there strong evidence of any sizeable mark-ups of price over marginal costs (indicating lower product market competition); in other sectors there was no positive mark-up although there was some evidence of a mark-down for electronic engineering.

It is also important to note that the impact on TFP of being located in a particular administrative region – relative to the benchmark region, the South East – was important for almost all industries, with effects that were sometimes significant and large.¹⁶ For example, computing plants in the North West, the East Midlands and to a lesser extent Wales had (*cet. par.*) higher TFP; while computing plants in Scotland did less well. In electronic engineering, plants located in all regions except the North West did worse than the South East. For motor vehicles, there was no evidence of (*cet. par.*) regional effects on TFP. In instrumental engineering, plants in the Midlands, Eastern England, London and Wales, did worse; while in pharmaceuticals only the Yorkshire-Humberside, the North

West and the South West had higher TFP vis-à-vis the South East. Lastly, plants located in the West Midlands and South West in aerospace had significantly higher TFP compared to the South East and other regions.

Table 3 here

Table 3 produces the main results showing the (*cet. par.*) impact of the distance index (measuring MAR spillovers at the industry-level) for plants of different sizes in the six advanced manufacturing industries; Figure 4 (below) produces a graphical version. Generally, there is evidence that the effect of greater co-location on smaller (larger) plants was generally negative (positive), with the exception of aerospace where a 1% increase in the distance index resulted in higher TFP of around 0.12-0.14% (slightly decreasing with size). For example, in the computers sector (SIC33), the effect of a 1% increase in the distance index on plants employing 5 workers was to reduce TFP by 0.04% but the effect was not significant for larger plants (Table 3, first data column). For electronic engineering (SIC34), the negative impact on TFP of co-locating is large for small plants (−0.31% for plants employing 5 workers), decreasing to no statistically significant impact for very large plants. There is a similar pattern for motor vehicles and instrumental engineering, although the negative effect of co-location on smaller plants is larger in motor vehicles and the positive effect on larger plants is bigger in instruments. Pharmaceuticals has a similar profile, but the negative impacts of being smaller are not statistically significant. Figure 4 shows more clearly the steepness of the elasticities for each industry, and the overall average impact of the distance index on TFP (highest overall for aerospace, and lowest for electronic engineering where no plants of any size benefit from agglomeration).

Figure 4 here

Alternative models for the six advanced manufacturing sectors

The results presented in the last section were based on the index using distances between plants belonging to the same 4-digit industry with a rate of decay of −0.05. To test the sensitivity of the results to alternative specifications of the distance index, we extend the results presented in Table 3 to include those obtained using different rates of decay and also plants belonging to wider sets of related industries rather than just their own industry. Table U.2 in the online appendix presents these extended results (along with a discussion), showing that the general conclusion reached in the previous section – which were based on just the intra-medium distance index – is in large part supported (indeed strengthened). Only in two sectors (aerospace and to some extent computing) is there evidence that spillovers are generally beneficial to plants of all sizes; for the others, small plants do not generally experience a positive TFP spillover if they co-locate. There is variability (see especially Figure U.3) depending on which distance index is used; but there is also some evidence that the results based on related industries generate higher estimates of spillovers than those based on within- industry specifications. This is possibly in line with prior expectations (spillovers are likely higher in larger related industry groupings with low rates of decay and lowest in specific industries with high rates of decay), but the evidence presented in the online appendix is more tentative in nature, and clearly would benefit from extending the methodology to other (including non-advanced) manufacturing sectors, and indeed services.

Potential implications for place-based policies and local industrial strategies

As noted in the review of the literature, there are, essentially, two different accounts or interpretations of the beneficial roles that spatial proximity is assumed to confer on firms, by improving their growth and productivity. The first is Porter's cluster theory. The spatial proximity or geographical concentration of firms in the same and closely related (both upstream and downstream) sectors of activity is assumed to be a key attribute, indeed, prerequisite, for the formation and functioning of specialised business clusters. Spatial proximity (the close co-location of firms) of itself does not equate to a functioning cluster, but it is assumed to play a fundamental role by facilitating and fostering a range of Marshallian localisation externalities, such as the attraction of a local pool of specialised and skilled labour, the local development of specialist intermediary firms and services, transfers and exchange of knowledge and information among local firms (spatial proximity is assumed to confer cognitive proximity), and local supportive institutions, that all contribute to the operation and development of a cluster as a functioning local industrial ecosystem. As such, the spatial proximity of similar and related firms, as the basis of clusters, is assumed to foster higher growth, innovation and productivity among the firms concerned.

The second account is the agglomeration argument. Strictly speaking agglomeration refers to the geographical concentration, usually in a city or an urban region, of a diverse range of firms, spanning several economic activities, both related and unrelated. Agglomeration, like clustering, is also assumed to produce various external economies and untraded interdependencies on which firms can draw – usually referred to as Jacobsian externalities – including a large and diverse labour pool, a large 'home' market of both suppliers and customers, extensive opportunities for new firm entrants, the promotion of innovation through competition and the availability of market niches, a dense infrastructure network that facilitates connectivity, and the like. Again, these positive agglomeration externalities are alleged to boost the economic performance of the local firms in the agglomeration. Studies have shown, for example, that doubling the size of a city is typically associated with an increase in the city's productivity of between 4-8 percent (see Li and Gibson, 2015). As in clusters, the spatial proximity of firms in an agglomeration is viewed as a key driver of firm growth and performance.

Both the clusters concept and the notion of agglomeration have attracted considerable attention from policymakers. Indeed, from the very start, Porter gave his 'cluster theory' an explicit policy dimension, arguing that clusters should be a central component of a policymaker's tool kit for boosting both local economic development and, in turn, national competitive advantage.

... governments should promote cluster formation and upgrading and the build-up of public or quasi-public goods that have a significant impact on many linked businesses. ... the aim of cluster policy is to reinforce the development of all clusters... Governments should not choose among clusters, because each one offers opportunities to improve productivity and support rising wages. Every cluster not only

contributes directly to national productivity but also affects the productivity of other clusters (Porter, 1998, p.89).

Porter argues that cluster policy is quite distinct from 'traditional' industrial policy in that it is not concerned with targeting 'desirable' or 'strategic' industries ('picking winners') that are then supported by selective subsidies or other financial inducements. Rather, cluster policy is about promoting and upgrading clusters of all sorts, regardless of their specialisms, in an effort to improve their productive performance. Government, working with the private sector, should reinforce and build on existing and emerging clusters rather than attempt to create entirely new ones.

Over the past 30 years or so, many countries and regions have pursued some sort of cluster-based industrial policy, not just in advanced economies but also in developing countries (see Wolman and Hincapie, 2014). The UK has been no exception to this appeal of the cluster concept to policy-makers. Similarly, much has been written in recent years, mainly by spatial economists, on the arguments in favour of agglomeration and encouraging bigger cities as a means of increasing productivity (Cheshire *et al.*, 2014). Whether the policy discussion is on clusters or agglomeration – and often the two are confusingly elided – the spatial proximity of firms is assumed to be of crucial beneficial importance.

The claims made for both clusters and agglomeration have of course been challenged, both on theoretical and policy grounds (on clusters, see, for example, Martin and Sunley, 2003; Duranton, 2011; on agglomeration, see Moomaw, 1983). As various commentators have observed, even some of those who have championed the cluster concept (for example, Delgado, Porter and Stern, 2012), have since questioned its policy usefulness: "So far there is little empirical evidence of the overall effectiveness of ... different cluster programs" (op cit p. 4). Moreover, according to Duranton (2011), not only are most empirical estimates of the impact of clustering on firm productivity modest at best, they are probably exaggerated. Our study in this paper of the impact of spatial proximity on firm productivity in some key UK manufacturing sectors does not offer much comfort to those national or local policy-makers who consider clusters an essential weapon in their industrial policy armoury. Several key issues remain unresolved. For example, just how spatially proximate do firms have to be to both produce and benefit from Marshallian-type localisation externalities? In a globalised world, with instant telecommunications and considerably enhanced mobility of capital, supply chains and knowledge networks have become ever more geographically dispersed, and with improvements in transport, workers now commute further to work than they once did. Thus, the importance of simple close physical spatial proximity may have become much less crucial for firm performance than it once was. Similarly, the geographical agglomeration of firms may itself generate diseconomies, such as higher land, wage and housing costs, congestion problems, pollution, pressure on infrastructure, and so forth, which may dent the advantages of a dense spatial proximity of firms.

Our main finding in this paper, namely that once various other factors are taken into account spatial proximity does not consistently emerge as a key determinant of total factor productivity in British advanced manufacturing firms, raises a caveat in relation to local industrial strategies or place-based policies aimed at promoting clusters or city-region agglomerations in order to increase local and national productivity. This is not to

argue that the spatial proximity of firms is unimportant, nor that place-based policies are misconceived. Our results suggest that cluster policies may achieve impact in the case of larger firms, but not necessarily for small firms, which are often viewed as the primary targets and beneficiaries of such policies. ‘Spatial proximity’ *per se* would not appear to be a key driver of small firm performance, and encouraging spatial proximity on its own will most likely prove an inadequate strategy. Further research is needed to explore why this may be so.

One of the intriguing aspects of the UK’s productivity puzzle is the existence and persistence of a long tail and lagging middle of low productivity firms, a problem that appears to be more pronounced in the older industrial regions. It is a problem that has been attributed in part to a lack of technological diffusion from high productivity firms to low productivity firms (Haldane, 2018). It could well be, therefore, that smaller firms lack absorptive capacity, that is the ability to internalise Marshallian-type externalities and agglomeration spillovers arising from their spatial proximity to other firms. This would mean that even when firms are spatially proximate they do not form effective clusters with interactive learning and collaborative linkages. If this is the case, then an obvious implication for industrial policy – in the UK case: the new national Industrial Strategy and associated Local Industrial Strategies – is to recognise the need to boost absorptive capacity in order to maximise the benefits of co-location (see also Harris and Yan, 2019). More research on this aspect of (small) firm performance in clusters and city-regions across the UK would help inform such policies.

At the same time, of course, the fact that the UK’s overall productivity performance in manufacturing is inferior to that of its main competitors may point to wider systemic problems and national policy failures (for example relating to education, skills, infrastructure, support for R&D and so on), though such ‘national’ problems are almost certain to have their own specific internal geographies. What does seem clear is that the positive influence of spatial proximity *per se* on the economic performance and productivity of firms is by no means a universal or ‘natural’ outcome, and hence not in itself a robust presumption on which to proclaim a case for a ‘place-based’ industrial policy.

Conclusions

It is generally assumed that clustering – the spatial proximity and geographical concentration of sectorally similar and related firms – increases both the productivity of the plants concerned, and, by implication, the overall productivity and performance of the wider geographical area, the region, in which the ‘cluster’ is situated. This assumption has become something of a ‘conventional wisdom’ in the academic literature. Such has been its academic visibility that the notion of clusters has also proved highly influential in policy circles, the belief being that measures and incentives to boost or even promote clusters is a valid instrument of both national and local industrial policy.

The UK has been no exception to this appeal of the cluster concept to policy-makers. As the manufacturing sector as a whole has declined in importance, as measured by its share of national employment, output and exports, and economic growth has become heavily dependent on financial and related service activities, especially those concentrated in

London, so policy attention has focused on the performance and potential of ‘advanced’ manufacturing activities as a means of achieving a more sectorally and spatially balanced economy. At the same time, there is considerable concern over what has become labelled as the ‘productivity puzzle’, the slowdown in productivity growth that has taken place not just since the financial crisis of 2007-8, as is often argued, but actually since the 1990s, if not earlier. Under these circumstances, the role of business clusters assumes particular salience. Is the decline in productivity growth due to the break-up of pre-existing clusters of manufacturing activity, perhaps because of the off-shoring of activity or the delocalisation of supply chains, and the consequential atrophy of the local industrial ecosystems that clusters are presumed to foster? Or is it the case that manufacturing clusters in the UK lack the critical mass to generate the positive externalities and spillovers that are assumed to accompany well-developed clusters? Is there scope for policy intervention to help strengthen and deepen clusters of advanced manufacturing, so as to boost local and national productivity? These are all pertinent issues.

The novelty of our approach in this paper is that we have tested for the impact of varying degrees of spatial proximity in six advanced manufacturing sectors (at 4-digit SIC level) and in wider sets of related industries, allowing different rates of decay in the impact of distance on co-located plants. We find that positive impacts of spatial proximity on firm productivity are by no means universal, and in all but two sectors the benefits appear to be significant only for larger plants (which presumably have sufficient absorptive capacity to take advantage of inter-firm spillovers and other such externalities). We also find other ‘place’ factors influence TFP, especially the impact of being located in particular regions, which are often larger geographically than narrowly defined spatial clusters. However, there is little evidence, after controlling for other firm and place effects, that being located in a major city leads to a positive TFP impact, while urbanization economies were not evident in four sectors. The overall finding is that the spatial proximity of similar and related firms in ‘clusters’ neither necessarily nor consistently leads to firms having higher levels of total factor productivity. This is particularly the case for small firms. In this respect, our findings provide no support for claims that small firms in particular benefit from geographical clustering.

Of course, this is not to argue that spatial proximity and co-location, bring no benefits to firms. Clustering and agglomeration are about more than spatial proximity per se, even though close proximity is supposed to encourage various traded and untraded spillovers and interdependencies among co-located firms. At the same firm productivity is determined by a host of factors other than spatial proximity to other similar, related or connected firms. The main message of this paper, however, is that spatial proximity is not a certain means of raising productivity growth, and clustering policies will need to do much more than just increasing co-location if they are to boost local, and national, productivity.

References

- Aarstad, J., Kvitastein, O. and Jakobsen, S-E. (2016) Related and unrelated variety as regional drivers of enterprise productivity and innovation: A multilevel study, *Research Policy*, **45**, 844-856.
- Åberg, Y. (1973) Regional productivity differences in Swedish manufacturing, *Regional and Urban Economics*, **3**, 131-155.
- Akerberg, D., Caves, K. and Frazer, G. (2015) Identification Properties of Recent Production Function Estimators, *Econometrica*, **83**, 2411-2451.
- Acs, Z., Anselin, L. and Varga, A. (2002) Patents and innovation counts as measures of regional production of new knowledge, *Research Policy*, **31** (7), 1069-1085.
- Agrawal, A. and Cockburn, I. (2003) The anchor tenant hypothesis: exploring the role of large, local, R&D-intensive firms in regional innovation systems, *International Journal of Industrial Organization*, **21** (9), 1227-53.
- Andersson, M. and Lööf, H. (2011) Agglomeration and productivity: evidence from firm-level data, *The Annals of Regional Science*, **46** (3), 601-620.
- Anselin, L., Varga, A. and Acs, Z. (1997) Local Geographic Spillovers between University Research and High Technology Innovations, *Journal of Urban Economics*, **42**, 422-448.
- Antonelli, C., Patrucco, P. and Quatraro, F. (2011) Productivity growth and pecuniary knowledge externalities; An empirical analysis of agglomeration economies in European regions, *Economic Geography*, **87**, 1, 23-50.
- Arrow, K. (1962) The Economic Implications of Learning by Doing, *The Review of Economic Studies*, **29**, 155-173.
- Audretsch, D., Falck, O. and Heblech, S. (2007) It's all in Marshall: The Impact of External Economies on Regional Dynamics, CESIFO Working Paper: Category 5: Fiscal Policy, Macroeconomics and Growth, 2094.
- Audretsch, D. and Feldman, M. (1996) R&D Spillovers and the Geography of Innovation and Production, *American Economic Review*, **86**, 630-640.
- Baldwin, J., Brown, W. M. and Rigby, D. (2010) Agglomeration Economies: Microdata Panel Estimates from Canadian Manufacturing, *Journal of Regional Science*, **50**, 915-934
- Barnes, T. and Gertler, M. (1999) *The New Industrial Geography: Regions, Regulations and Institutions*, London, UK and New York, NY: Routledge.
- Bartelsman, E. and Dhrymes, P. (1998) Productivity Dynamics: U.S. Manufacturing Plants, 1972-1986, *Journal of Productivity Analysis*, **9**, 5-34.
- Black, D. and Henderson, V. (1999) A theory of urban growth, *Journal of Political Economy*, **107** (2), 252-84.
- Boschma, R. (2005) Proximity and innovation: A critical assessment, *Regional Studies*, **39**, 1, 61-74.
- Boschma R. and Iammarino, S. (2009) Related variety, trade linkages, and regional growth in Italy, *Economic Geography*, **85**, 3, 289-311.
- Brühlhart, M. and Mathys, N. (2008) Sectoral agglomeration economies in a panel of European regions, *Regional Science and Urban Economics*, **38**, 348-362.

- Bun, M. and Sarafidis, V. (2013) Dynamic panel data models, Amsterdam School of Economics, Discussion paper 2013/01.
- Cainelli, G., Ganau, R. and Iacobucci, D. (2016) Do geographic concentration and vertically related variety foster firm productivity? Micro-evidence from Italy, *Growth and Change*, **47**, 2, 197-217.
- Capello, R. (2002) Entrepreneurship and spatial externalities: Theory and measurement, *The Annals of Regional Science*, **36**, 387-402.
- Cheshire, P., Nathan, M. and Overman, H. (2014) *Urban Economics and Urban Policy: Challenging Conventional Policy Wisdom*. Cheltenham: Edward Elgar.
- Ciccone, A. and Hall, R. (1996) Productivity and the Density of Economic Activity, *The American Economic Review*, **86**, 54-70.
- Ciccone, A. (2002) Agglomeration effects in Europe, *European Economic Review*, **46**, 213-227.
- Combes, P., Duranton, G., Gobillon, L. and Roux, S. (2008) Estimating Agglomeration Economies with History, Geology, and Worker Effects, in E. Glaeser (ed.), *Agglomeration Economics*. Chicago: University of Chicago Press. 15-65.
- Crepon, B., Duguet, E. and Mairesse, J. (1998) Research, Innovation And Productivity: An Econometric Analysis At The Firm Level, *Economics of Innovation and New Technology*, **7**, 115-158.
- De Groot, H., Poot, J. and Smit, M. (2016) Which Agglomeration Externalities Matter Most and Why?, *Journal of Economic Surveys*, **30**, 756-782.
- Del Gatto, M., Di Liberto, A. and Petraglia, C. (2011) Measuring Productivity, *Journal of Economic Surveys*, **25**, 952-1008.
- Delgado, M. Porter, M. and Stern, S. (2014) Clusters, Convergence, and Economic Performance, *Research Policy*, **43**, 1785-1799.
- Department for Business, Energy and Industrial Strategy (2017) *Density-Based Industrial Clustering: Identifying Industrial Clusters in the UK*, London: HMSO.
- Department of the Environment, Transport and Regions (DETR) (2000) *Planning for Clusters*. London: HMSO.
- Department of Trade and Industry (DTI) (1998) *Our Competitive Future: Building the Knowledge-Driven Economy*. London: HMSO.
- Devereux, M., Griffith, R. and Simpson, H. (2007) Firm location decisions, regional grants and agglomeration externalities, *Journal of Public Economics*, **91**, 413-435.
- Dixit A. and Stiglitz, J. (1977) Monopolistic competition and optimum product diversity. *American Economic Review*, **67** (3), 297-308.
- Drennan, M. (2002) *The information economy and American cities*, Baltimore: Johns Hopkins University Press.
- Driffield, N. and Love, J. (2007) Linking FDI motivation and host economy productivity effects: conceptual and empirical analysis, *Journal of International Business Studies*, **38**, 460-473.
- Duranton, G. (2011) California Dreamin': The Feeble Case for Cluster Policies, *Review of Economic Analysis*, **3**, 3-45.

- Duranton, G. and Puga, D. (2004) Micro-foundations of urban agglomeration economies, in J. V. Henderson and T. Jacques-François (eds), *Handbook of Regional and Urban Economics*. Amsterdam; Oxford: Elsevier. 2063-2117.
- Ehrl, P. (2013) Agglomeration economies with consistent productivity estimates. *Regional Science and Urban Economics*, **43** (2013) 751–763.
- Ellison, G., Glaeser, E. and Kerr, W. (2010) What Causes Industry Agglomeration? Evidence from Coagglomeration Patterns, *American Economic Review*, **100**, 1195-1213.
- Eriksson, R. (2011) Localized spillovers and knowledge flows: how does proximity influence the performance of plants? *Economic Geography*, **87**, 2, 127-152.
- Eriksson, R. and Lindgren, U. (2009) Localized mobility clusters: impacts of labour market externalities on firm performance, *Economic Geography*, **9**, 1, 33-53.
- Faggio, G., Silva, O. and Strange, W., (2017) Heterogeneous agglomeration, *The Review of Economics and Statistics*, **99**, 1, 80-94.
- Falcioglu, P. (2011) Location and determinants of productivity: The case of manufacturing industry in Turkey, *Emerging Markets Finance and Trade*, **47**, sup5, 86-96.
- Feldman, M. (2003) The locational dynamics of the US biotechnology industry: knowledge externalities and the anchor hypothesis, *Industry and Innovation*, **10** (3), 311-28.
- Florida, R. (2002) *The rise of the creative class and how its transforming work, leisure community and everyday life*, New York, NY, USA: Basic Books.
- Frenken, K., Van Oort, F. and Verburg, T. (2007) Related variety, unrelated variety and regional economic growth, *Regional Studies*, **41**, 5, 685-697.
- Fujita, M. and Thisse, J.-F. (2002) *Economics of Agglomeration: Cities, Industrial Location, and Regional Growth*, Cambridge, UK and New York, NY, USA: Cambridge University Press.
- Gandhi, A., Navarro, S. and Rivers, D. (2012) On the identification of production functions: how heterogenous is productivity, Discussion Paper No. 288, Collegio Carlos Alberto, Moncalieri.
- Gertler, M. (2003) Tacit Knowledge and the Economic Geography of Context, or the Undefinable Tacitness of Being (There), *Journal of Economic Geography*, **3**, 75-99.
- Glaeser, E., Kolko, J. and Saiz, A. (2001) Consumer City, *Journal of Economic Geography*, **1** (1), 27-50.
- Glaeser, E., Kallal, H., Schinkmann, J. and Shleifer, A. (1992) Growth in cities, *Journal of Political Economy*, **100** (1), 126-52.
- Graham, D. (2009) Identifying urbanisation and localisation externalities in manufacturing and service industries, *Papers in Regional Science*, **88**, 63-84.
- Graham, D., Melo, P., Jiwattanakulpaisarn, P. and Noland, R. (2010) Testing for causality between productivity and agglomeration economies, *Journal of Regional Science*, **50**, 935-951.
- Greenstone, M., Hornbeck, R., and Moretti, E. (2010) Identifying Agglomeration Spillovers: Evidence from Winners and Losers of Large Plant Opening, *Journal of Political Economy*, **118**, 536-598.

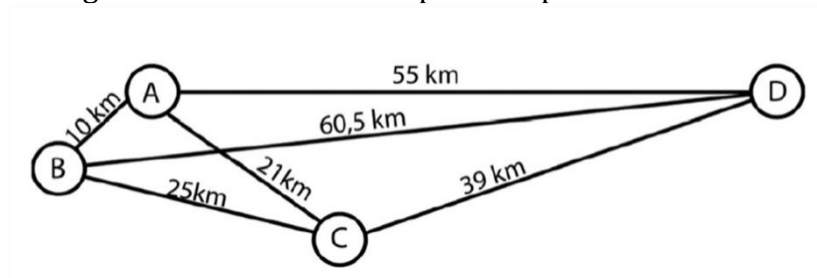
- Griffith, R. (1999) Using the ARD Establishment Level Data to Look at Foreign Ownership and Productivity in the United Kingdom, *Economic Journal*, **109**, F416-42.
- Griliches, Z. (1979) Issues in assessing the contribution of research and development to productivity slowdown, *Bell Journal of Economics*, **10** (1), 92-116.
- Griliches, Z. (1992) The search for R&D spillovers, *Scandinavian Journal of Economics*, **94** (supplement), S29-47.
- Haldane, A. (2018) The UK's Productivity Problem: Hub No Spokes. Bank of England Speech. Academy of Social Sciences Annual Lecture, London 28 June 2018.
- Harris, R (2017) Regional Competitiveness and Economic Growth: The Evolution of Explanatory Models, in *Handbook of Regions and Competitiveness Contemporary Theories and Perspectives on Economic Development* by R. Huggins and P. Thompson (eds.) Edward Elgar, 80-116.
- Harris, R. (2005b) *Deriving measures of plant-level capital stock in UK manufacturing, 1973-2001*, Report to the DTI. Available at http://www.gla.ac.uk/t4/economics/files/harris_2005capstockfinalreport.pdf.
- Harris, R. and Moffat, J. (2012) Is productivity higher in British cities? *Journal of Regional Science*, **52**, 762-786.
- Harris, R. and Moffat, J. (2015) Plant-level determinants of total factor productivity in Great Britain, 1997-2008, *Journal of Productivity Analysis*, **44**(1), 1-20.
- Harris, R. and Yan, J. (2019) The Measurement of Absorptive Capacity from an Economics Perspective: Definition, Measurement and Importance, *Journal of Economic Surveys*, **33**(3), 729-756.
- Harris, R. and Le, T. (2018) Absorptive Capacity in New Zealand Firms: Measurement and Importance, *Science and Public Policy*, **46**(2), 290-309.
- Harris, R. and Drinkwater, S. (2000) UK Plant and Machinery Capital Stocks and Plant Closures, *Oxford Bulletin of Economics and Statistics*, **62**, 243-265.
- Harris, R., Moffat, J. and Kravtsova, V. (2011) In Search of 'W', *Spatial Economic Analysis*, **6**, 249-270.
- Harris, R. (2002) Foreign Ownership and Productivity in the United Kingdom—Some Issues When Using the ARD Establishment Level Data, *Scottish Journal of Political Economy*, **49**, 318-335.
- Harris, R. (2005a) Economics of the Workplace: Special Issue Editorial, *Scottish Journal of Political Economy*, **52**, 323-343.
- HC (2018) Industrial Strategy, House of Commons Briefing Paper 7682. Available from: <https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7682>.
- Henderson, J. V. (1986) Efficiency of resource usage and city size, *Journal of Urban Economics*, **19**, 47-70.
- Henderson, J. V. (2003) Marshall's Scale Economies, *Journal of Urban Economics*, **53**, 1-28.
- Jacobs, J. (1970) *The Economy of Cities*, New York, NY, USA: Vintage.
- Jacobs, J. (1986) *Cities and the Wealth of Nations*, New York, NY, USA: Vintage.
- Kelegian, H. (2008) A Spatial J-Test for Model Specification against a Single or a Set of Non-nested Alternatives, *Letters in Spatial and Resource Sciences*, **1**, 3-11.

- Knoben, J., Arikian, A., Van Oort, F. and Raspe, O. (2016) Agglomeration and firm performance: One firm's medicine is another firm's poison, *Environment and Planning A*, **48**, 1, 132-153.
- Koo, J. (2005) Technological spillovers, agglomeration, and regional economic development, *Journal of Planning Literature*, **20** (2), 99-115.
- Levinsohn, J. and Petrin, A. (2003) Estimating Production Functions Using Inputs to Control for Unobservables, *The Review of Economic Studies*, **70**, 317-341.
- Li, C. and Gibson, J. (2015) City Scale and Productivity in China, *Economics Letters*, **131**, 86-90.
- Lööf, H. and Nabavi, P. (2015) Knowledge Spillovers, Productivity and Patent, *Annals of Regional Science*, **55**, 249-263.
- López, R. and Südekum, J. (2009) Vertical Industry relations, Spillovers, and productivity: Evidence from Chilean Plants, *Journal of Regional Science*, **49**, 721-747.
- Lychagin, S. (2016) Spillovers, Absorptive Capacity and Agglomeration, *Journal of Urban Economics*, **96**, 17-35.
- Marshall, A. (1890) *Principles of Economics*. London: Macmillan.
- Martin, R. and Sunley, P. (2003) Deconstructing clusters: Chaotic concept or policy panacea? *Journal of Economic Geography*, **3**, 5-35.
- Martin, P., Mayer, T. and Mayneris, F. (2011) Spatial concentration and plant-level productivity in France, *Journal of Urban Economics*, **69**, 182-195.
- Martin, R. (2008) Productivity dispersion, competition and productivity measurement, CEP Discussion Paper 692, CEP.
- Melitz, M. and Ottaviano, G. (2008) Market Size, Trade, and Productivity, *Review of Economic Studies*, **75**, 295-316.
- Moomaw, R. (1983) Is population scale a worthless surrogate for business agglomeration economies?, *Regional Science and Urban Economics*, **13**, 525-545.
- Nakamura, R. (1985) Agglomeration economies in urban manufacturing industries: A case of Japanese cities, *Journal of Urban Economics*, **17**, 108-124.
- Neary, P. (2001) Of hype and hyperbolas: introducing the new economic geography, *Journal of Economic Literature*, **39** (2), 536-561.
- Olley, G. S. and Pakes, A. (1996) The Dynamics of Productivity in the Telecommunications Equipment Industry, *Econometrica*, **64**, 1263-1297.
- ONS (2012) Annual Respondents Database, 1973-2008: Secure Access. [data collection]. 3rd Edition. UK Data Service. SN: 6644 <http://doi.org/10.5255/UKDA-SN-6644-5>.
- ONS (2017) Business Structure Database, 2008-16: Secure Access. [data collection]. 9th Edition. UK Data Service. SN: 6697 <http://doi.org/10.5255/UKDA-SN-6697-9>.
- ONS (2018) Annual Business Survey, 2008-16: Secure Access. [data collection]. 9th Edition. UK Data Service. SN: 7451 <http://doi.org/10.5255/UKDA-SN-7451-9>.
- Oulton, N. (1997) The ABI respondents database: A new resource for industrial economics research, *Economic Trends*, **528**, 46-57.
- Overman, H, Gibbons, S. and Tucci, A. (2009) The Case for Agglomeration Economies, *Manchester Independent Economics Review*. Manchester, Available at: <http://www.manchester-review.org.uk/projects/view/?id=718>.

- Papalia, R. and Bertarelli, S. (2009) The Role of Local Agglomeration Economies and Regional Characteristics in Attracting FDI: Italian Evidence, *International Journal of the Economics of Business*, **16**, 161-188.
- Porter, M. (1990) *The Competitive Advantage of Nations*, London: Macmillan.
- Porter, M. (1998a) Clusters and the new economics of competitiveness, *Harvard Business Review* (December), 77-90.
- Porter, M. (1998b) *On Competition*, Cambridge, MA: Harvard Business School Press.
- Porter, M. (1996) Competitive advantage, agglomeration economies, and regional policy, *International Regional Science Review*, **19**, 1, 85-94.
- Quigley, J. (1998) Urban diversity and economic growth, *Journal of Economic Perspectives*, **12** (2), 127-38.
- Raspe, O. and Van Oort, F. (2011) Firm heterogeneity, productivity and spatially bounded knowledge externalities, *Socio-Economic Planning Sciences*, **45**, 38-47.
- Rice, P., Venables, A. and Patacchini, E. (2006) Spatial determinants of productivity: Analysis for the regions of Great Britain, *Regional Science and Urban Economics*, **36**, 727-752.
- Rigby D. and Brown, W. (2015) Who benefits from agglomeration? *Regional Studies*, **49**, 1, 28-43.
- Romer, P. (1986) Increasing Returns and Long-run Growth, *Journal of Political Economy*, **94**, 1002-1037.
- Roodman, D. (2009) A Note on the Theme of Too Many Instruments, *Oxford Bulletin of Economics and Statistics*, **71**, 135-158.
- Scholl, T. and Brenner, T. (2016) Detecting Spatial Clustering Using a Firm-Level Cluster Index, *Regional Studies*, **50**:6, 1054-1068.
- Scitovsky, T. (1954) Two concepts of external economies, *Journal of Political Economy*, **62** (2), 143-51.
- Segal, D. (1976) Are There Returns to Scale in City Size?, *The Review of Economics and Statistics*, **58**, 339-350.
- Slaper, T., Harmon, K. and Rubin, B. (2018) Industry clusters and regional economic performance: A study across US metropolitan statistical areas, *Economic Development Quarterly*, **32**, 1, 44-59.
- Sveikauskas, L. (1975) The Productivity of Cities, *The Quarterly Journal of Economics*, **89**, 393-413.
- Swords, J. (2013) Michael Porter's cluster theory as a local and regional development tool: The rise and fall of cluster policy in the UK, *Local Economy*, **28**, 369-383.
- U.S. cluster mapping project (2014) *Cluster Mapping*. Harvard Business School and U.S. Economic development Administration. Available from: <http://www.clustermapping.us>.
- Van Beveren, I. (2012) Total Factor Productivity Estimation: A Practical Review, *Journal of Economic Surveys*, **26**, 98-128.
- Van der Panne, G. (2004) Agglomeration externalities: Marshall versus Jacobs, *Journal of Evolutionary Economics*, **14**, 593-604.

- Van Oort, F. (2007) Spatial and sectorial composition effects of agglomeration economies in the Netherlands, *Papers in Regional Science*, **86** (1), 5-30.
- van Stel, A. and Nieuwenhuijsen, H. (2004) Knowledge spillovers and economic growth: an analysis using data of Dutch regions in the period 1987-1995, *Regional Studies*, **38** (4), 393-407.
- Venables, A. (2011) Productivity in cities: self-selection and sorting, *Journal of Economic Geography*, **11**, 241-251.
- Wang, S. and Zhao, M. (2018) A tale of two distances: a study of technological distance, geographic distance and multilocation firms, *Journal of Economic Geography*, **18**(5), 1091-1120.
- Wixe, S. (2015) The impact of spatial externalities: Skills, education and plant productivity, *Regional Studies*, **49**, 12, 2053-2069.
- Wixe, S. and Andersson, M. (2017) Which types of relatedness matter in regional growth? Industry, occupation and education, *Regional Studies*, **51**, 4, 523-536.
- Wolman, H. and Hincapie, D. (2014) Clusters and cluster-based development policies, *Economic Development Quarterly*, **29**, 135-149.

Figure 1: Calculating the distance index: simple example



Source: Scholl and Brenner (2016)

Figure 2: Impact of different decay functions on distance index

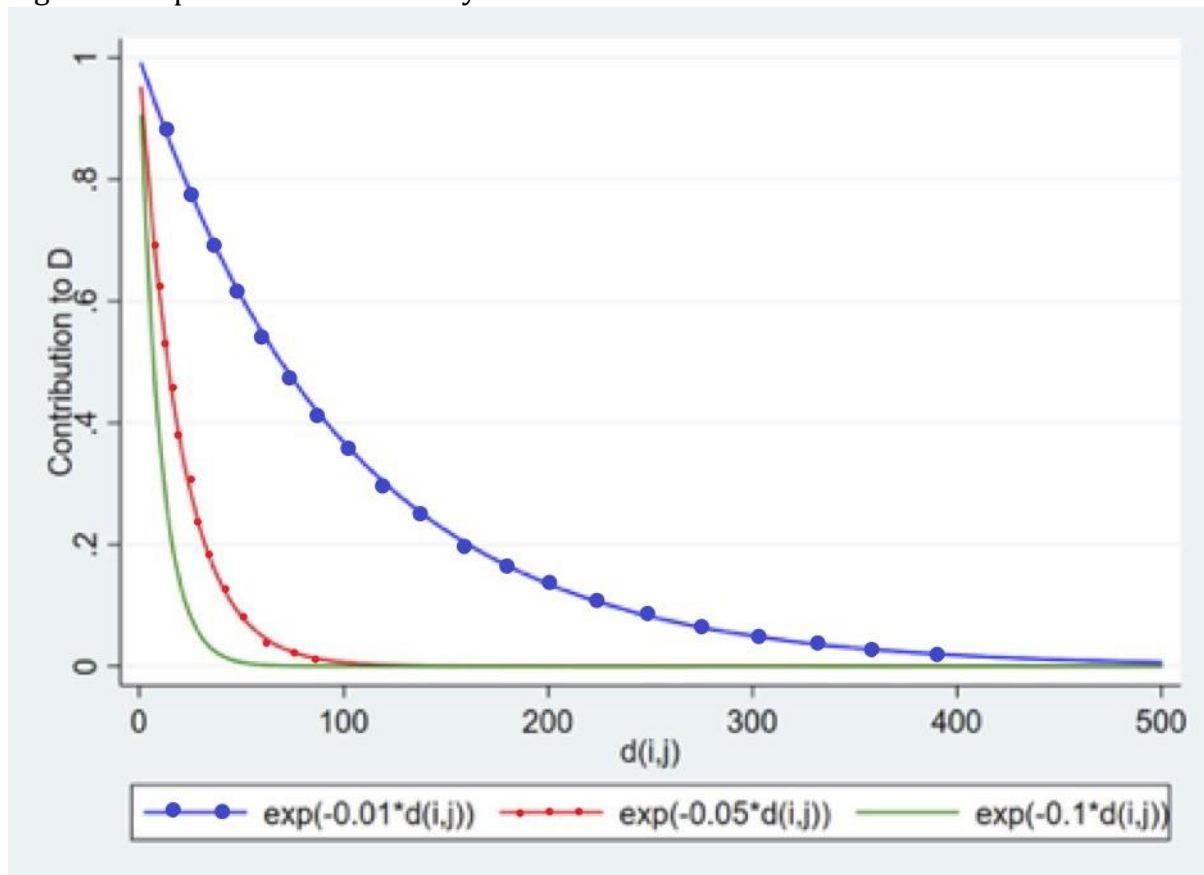
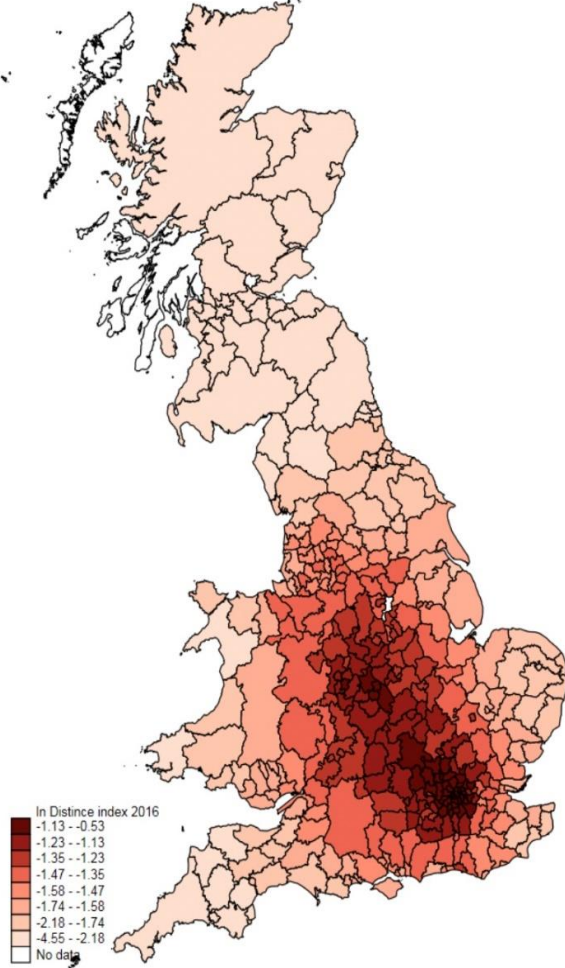
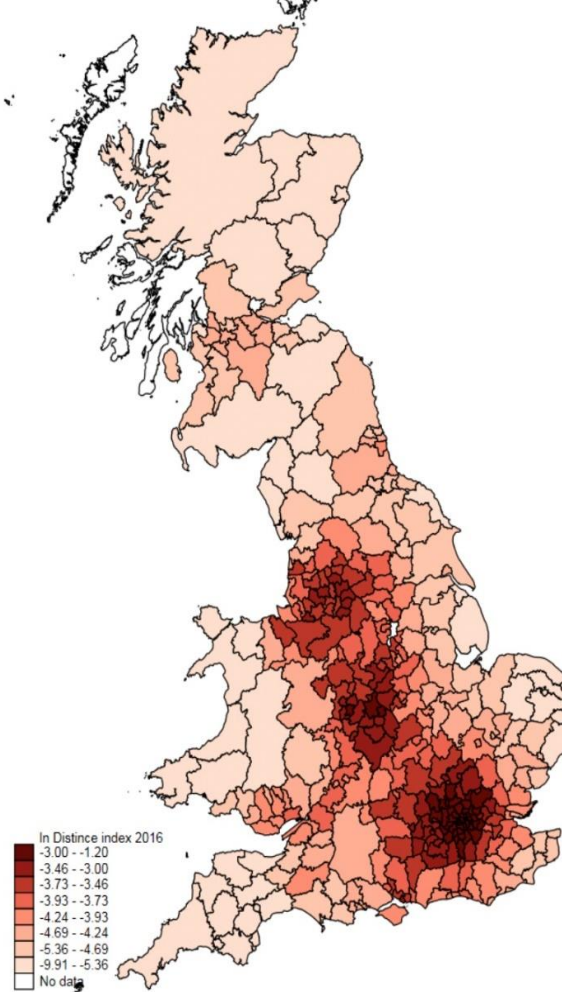


Figure 3: Average \ln Distance by local authority, 2016: 6 sectors in manufacturing

(a) Low decay $e^{-0.01(d_{i,j})}$ 4-digit SIC



(b) Medium decay $e^{-0.05(d_{i,j})}$ 4-digit SIC



(c) High decay $e^{-0.10(d_{i,j})}$ 4-digit SIC

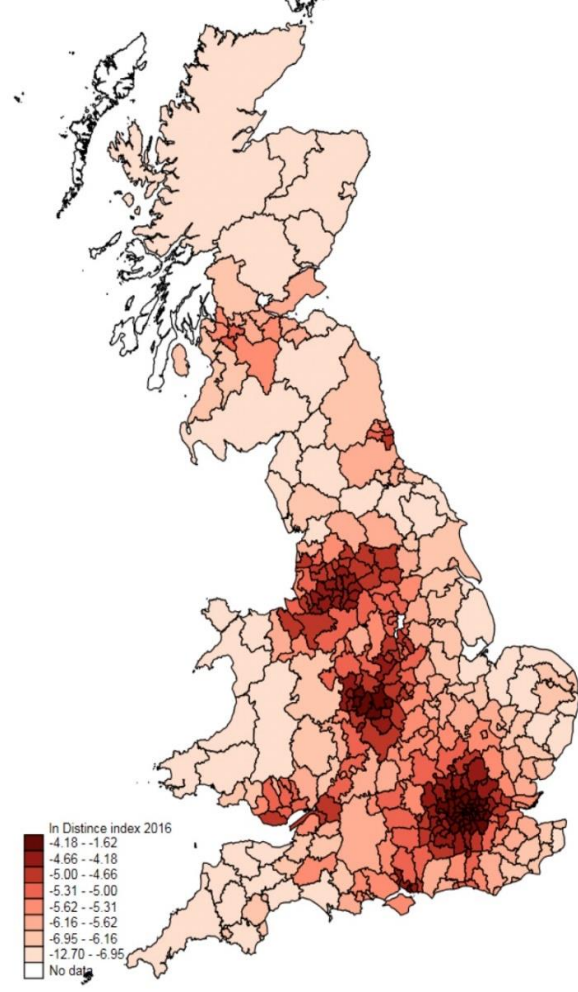
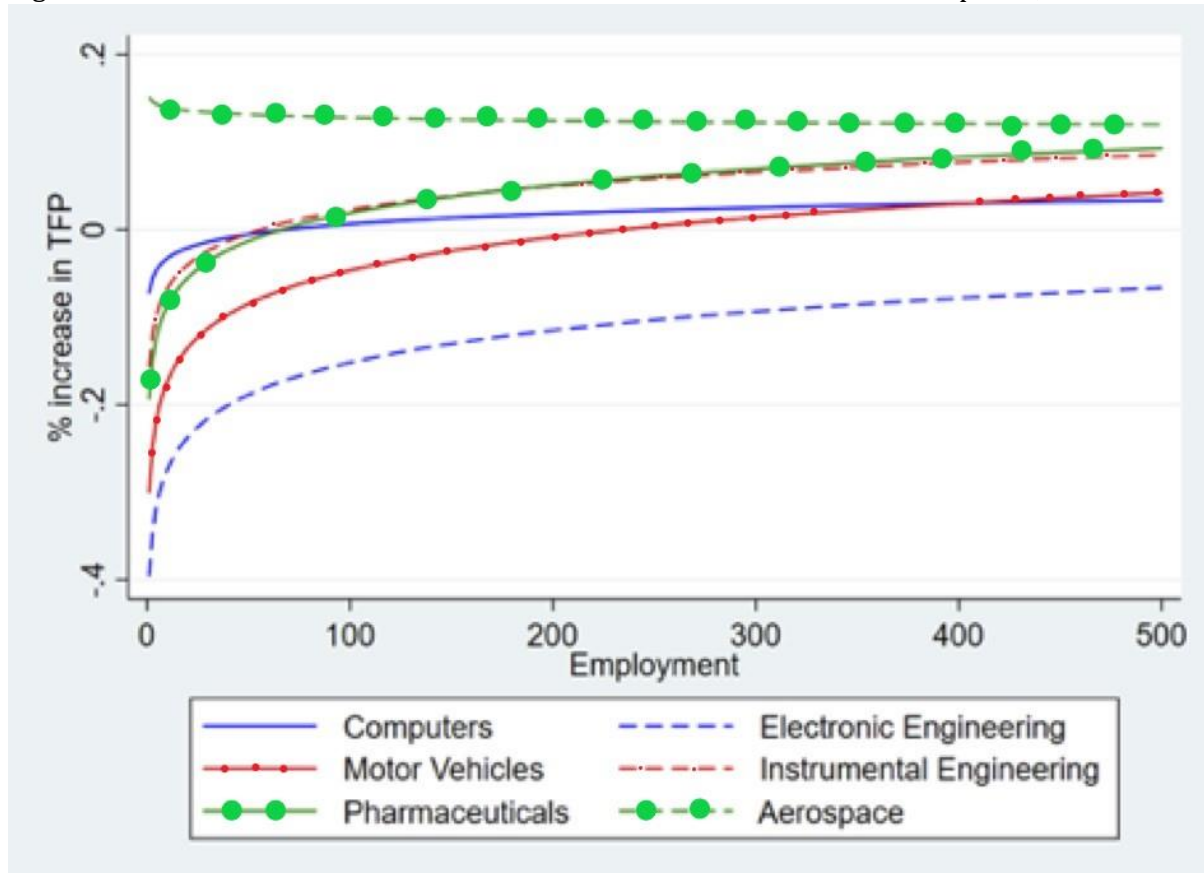


Figure 4: Effect of a 1% increase in distance index on TFP for different sized plants, 1984-2016



Source: based on model estimates in Table 3

Table 1: Definitions of variables used – 6 advanced manufacturing sectors, 1984-2016

Variable	Definition	Mean	Std. Dev.	Source ^a
<i>ln</i> Gross Output	<i>ln</i> real gross output (£m 2000 prices)	-0.160	1.989	ABS
<i>ln</i> Intermediate Inputs	<i>ln</i> intermediate inputs (gross output - GVA) (£m 2000 prices)	-0.951	2.204	ABS
<i>ln</i> Employment	<i>ln</i> numbers employed in plant	2.516	1.741	ABS
<i>ln</i> Capital	<i>ln</i> plant and machinery capital stock (£m 1995 prices) plus real value hires. Source: Harris and Drinkwater (2000, updated)	4.815	2.560	ABS
<i>ln</i> Distance (intra-low)	<i>ln</i> distance index based on 4-digit industries (low decay, $e^{-0.01(d_{i,j})}$)	-1.592	0.638	BSD
<i>ln</i> Distance (intra-medium)	<i>ln</i> distance index based on 4-digit industries (medium decay, $e^{-0.05(d_{i,j})}$)	-3.910	1.285	BSD
<i>ln</i> Distance (intra-high)	<i>ln</i> distance index based on 4-digit industries (high decay, $e^{-0.10(d_{i,j})}$)	-5.097	1.696	BSD
<i>ln</i> Distance (inter-low)	<i>ln</i> distance index based on related industry groupings (low decay, $e^{-0.01(d_{i,j})}$)	-1.622	0.538	BSD
<i>ln</i> Distance (inter-medium)	<i>ln</i> distance index based on related industry groupings (medium decay, $e^{-0.05(d_{i,j})}$)	-3.881	0.896	BSD
<i>ln</i> Distance (inter-high)	<i>ln</i> distance index based on related industry groupings (high decay, $e^{-0.10(d_{i,j})}$)	-4.957	1.045	BSD
<i>ln</i> Age	<i>ln</i> number of years since year of opening	1.721	1.035	ABS
Single-Plant Enterprise	Dummy coded 1 if plant comprises a single-plant enterprise	0.353	0.478	ABS
Multi-Region Enterprise	Dummy coded 1 if plant belongs to an enterprise operating plants in more than one UK region	0.523	0.499	ABS
Multi-SIC Enterprise	Dummy coded 1 if enterprise has more than one 4-digit SIC80 across plants it owns	0.360	0.480	ABS
USA	Dummy coded 1 if plant is US-owned	0.083	0.276	ABS
EU	Dummy coded 1 if plant is EU-owned	0.092	0.289	ABS
OFO	Dummy coded 1 if plant is other foreign-owned	0.024	0.153	ABS
Urbanisation	<i>ln</i> proportion of the 206 4-digit SIC80 industries in each LA in which plant is located - Jacobsian spillovers	-0.708	0.257	ABS
<i>ln</i> Herfindahl Index	<i>ln</i> Herfindahl index of industry concentration (3-digit level)	-2.605	0.786	ABS
Cities	Dummy coded 1 if plant is located in 'core' city (defined by NUTS3 code) ^b	0.148	0.355	ABS
Industry gross output	Real gross output (£m 2000 prices) at 3-digit SIC level	9.945	0.773	ABS
Region	Dummies coded 1 if plant is located in particular Government Office Region			ABS
Unweighted N		98,086		

^a Source: ONS (2012, 2017, 2018)^b These are London, Manchester, Birmingham, Glasgow, Edinburgh, Cardiff, Tyneside, Liverpool, Bristol, Nottingham, Leicester and Coventry; i.e., either capitals (i.e., Cardiff and Edinburgh) or they met the criteria of (in 2001) employing over 250,000 with a population density of 20+ persons per hectare; or they had employment of over 100,000 and densities of 30+ persons per hectare. They closely accord with the definition of 'core' cities used in Great Britain (see <http://www.corecities.com/>). Thus 'urban areas' that incorporate large hinterlands (e.g., Leeds) are excluded on the population density criterion.

Table 2 Means of $Distance_i$, 2014-16

	<u>Intra</u>			<u>Inter</u>		
	Low, $e^{-0.01(d_{i,j})}$	Medium, $e^{-0.05(d_{i,j})}$	High, $e^{-0.10(d_{i,j})}$	Low, $e^{-0.01(d_{i,j})}$	Medium, $e^{-0.05(d_{i,j})}$	High, $e^{-0.10(d_{i,j})}$
Motor Vehicles (SIC35)	0.275	0.046	0.021	0.247	0.033	0.013
Electronic Engineering (SIC34)	0.236	0.037	0.017	0.219	0.028	0.010
Computers (SIC33)	0.228	0.037	0.016	0.221	0.029	0.011
Instrumental Engineering (SIC37)	0.227	0.032	0.014	0.221	0.028	0.010
Aerospace (SIC364)	0.226	0.029	0.012	0.221	0.028	0.011
Pharmaceuticals (SIC257)	0.221	0.031	0.012	0.216	0.031	0.013

Source: see Table 1 and text

Table 3: Long-run (weighted) impact of \ln Distance based on 4-digit industry (medium decay, $e^{-0.05(d_{i,j})}$) on TFP by size of plant, 1984-2016 (Great Britain)

	Computers SIC33	Electronic Engineering SIC34	Motor Vehicles SIC35	Instrumental Engineering SIC37	Pharmaceuticals SIC257	Aerospace SIC364
\ln Distance	-0.072**	-0.396***	-0.300*	-0.157***	-0.193	0.151***
\ln Distance \times \ln employment	0.017*	0.053***	0.055**	0.039***	0.046*	-0.005
Distance \times 5 employees	-0.044**	-0.310***	-0.211*	-0.094***	-0.119	0.143***
Distance \times 50 employees	-0.005	-0.188***	-0.085	-0.004	-0.013	0.131***
Distance \times 500 employees	0.035	-0.065	0.042	0.087***	0.094	0.119***

Source: based on model estimates in Table U.1 (online appendix)

Endnotes

¹ This list, of course, bears some similarity to the triad of localisation externalities invoked by Alfred Marshall (1890) in his much earlier discussion of industrial districts. Porter's cluster concept is derived from Marshall's industrial district notion, updated and extended to embrace ideas from businesses economics on the nature of firm competition and competitive advantage.

² For a more comprehensive survey of the literature, see De Groot *et al.* (2016), Harris (2017) and Harris and Moffat (2012). The online appendix also provides a longer version of this section.

³ At the outset, it is important to note that in the empirical work we are treating 'clusters' as co-located plants in the same or related industries, where 'related' refers to mostly technical inter dependencies such as 'supply-chain' linkages. The notion of a cluster as co-located plants belonging to diverse industries is not the central focus of this study, although we discuss the distinctions in more detail below.

⁴ De Groot *et al.* (2016) have analysed 73 journal articles which build on the seminal work of Glaeser *et al.* (1992) and find a very mixed set of results (although perhaps more weight in favour of Jacobsian spillovers, particularly for papers related to city growth, which may not be surprising).

⁵ The distinction between intra- and inter-industry spillovers is often blurred if related industries (that are linked technologically, share labour, or share knowledge) are classified as part of a 'cluster' (see Delgado *et al.*, 2014) while colocation of industries (e.g., in cities) with weaker links lead to urbanisation externalities.

⁶ For a detailed description of the ARD and discussion of several issues concerning its appropriate use, see Oulton (1997), Griffith (1999), and Harris (2002, 2005a).

⁷ Ehrl (2013) sets out the approach and underlying assumptions. Since individual firm level prices are not observed, and thus by necessity firm's nominal gross output is deflated by *industry* price to obtain output in constant prices, then if firm prices depart systematically from the average industry price level, estimating the production function results in biased parameter estimates because of the omitted firm price variable. Using a Dixit and Stiglitz (1977) CES firm-level demand function:

$$y_{it}^d = -\sigma(p_{it} - p_{it}) + q_{it} + u_{it}^d$$

where y_{it}^d is the (logged) demand for output from firm i ; σ is the constant elasticity of demand; q_{it} is an aggregate demand shifter; and u_{it}^d represents demand shocks faced by the firm. Combining the demand function with the production function and noting that $y_{it}^d = r_{it} - p_{it}$ (where r_{it} is industry total revenue) results in equation (1).

⁸ Estimators (such as Olley and Pakes, 1996; Levinsohn and Petrin, 2003) that purport to overcome these endogeneity issues are based on assumptions we believe are more restrictive than those implied by system-GMM (Ackerberg *et al.*, 2015). In particular, these estimators do not allow for fixed effects, which previous work has shown to be important because the distribution of productivity is persistent over time (see, for instance, Bartelsman and Dhrymes, 1998; Martin, 2008). Note, like the Olley-Pakes approach, system-GMM is used to overcome the bias that would arise from OLS estimation if firms make decisions on factor inputs based on the value of the TFP shock (error term), which is unobservable to the researcher. Del Gatto *et al.* (2011) and Van Beveren (2011) provide useful surveys on these different approaches to measuring TFP.

⁹ Intermediate inputs cover materials, fuels, semi- and finished-goods and (especially business) services used in the production of new goods and services. We are not estimating a gross valued-added function because we do not want to impose weak separability (capital and labour are separable from intermediate inputs in production) and thus homogeneity with respect to α_M - see Gandhi *et al.* (2012) for a discussion.

¹⁰ Figure U.1 in the online appendix provides information on the groupings of related industries.

¹¹ If plants i and j are located in the same postcode district $d_{i,j}$ is assumed to be half of the distance between that postcode district and the closest (distinct) postcode district.

¹² Note, the maps are based on different percentile cut-off points in Figure 3 (using one set of points would hide the differences obtained when using different decay functions). A set of maps based on wider 'clusters' is available in the online appendix (Figure U.2); these show patterns very similar to the ones based on intra-industry indices (Figure 3).

¹³ Stata reports tests for the first-differenced residuals, thus there should be evidence of significant negative first order serial correlation in differenced residuals and no evidence of second order serial correlation in the differenced residuals, which is the case here.

¹⁴ That is, we use Roodman's suggested approach of typically using only the lagged values of the particular variable being instrumented, rather than instruments based on the lagged values of all endogenous variables (which often leads to over-instrumentation).

¹⁵ Note, our results are consistent with *a priori* expectations and previous work (cf. Harris and Moffat, 2012, 2015).

¹⁶ The results for ‘regional’ effects are more mixed across the different models estimated for each sector depending on which distance index was used. Thus here, comments are confined to those obtained using the intra-medium distance measure.